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THE FORCE DELIVERY OF REMOVABLE ORTHODONTIC BUCCAL RETRACTORS OF SMALLER DIAMETER WIRES: AN IN VITRO STUDY

by

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DEDICATION

THIS DESSERTATION IS DEDICATED TO MY LATE FATHER W.R. MOGOREGI AND MOTHER M.M MOGOREGI WHO INSPIRED ME.

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Prof. P. Hlongwa

DECLARATION

I, Pitso Fairbridge Mogoregi, declare that the dissertation I am herewith submitting for the degree MChD (Orthodontics) at the University of Pretoria is my own work and has not been submitted for any other degree at any other university.

Pitso Fairbridge Mogoregi

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SUMMARY

Load deflection rate (LDR) refers to the amount of force produced per unit deflection. A buccal retractor on a removable orthodontic appliance is commonly used to retract an upper canine. The traditional unsupported 0.7mm retractor is difficult to adjust and unstable in the vertical direction. Zietsman and Botha (2000) suggested a supported retractor by inserting the distal leg of a 0.5mm retractor in a tube which is soldered onto a molar clasp or continues into the palatal acrylic for more support.

The aim of this study was to assess the force delivery of removable orthodontic buccal retractors of smaller diameter wires. In addition, the relation of load deflection rate (LDR) to coil type, wire diameter and wire length was also examined.

Two different coils, the standard and reverse coil types, were made using three different wire sizes namely the 0.020, 0.022 and 0.028 inch diameter wires. The 0.028 inch diameter wire was used as a control. Unitek stainless steel wires were used. The wires were mounted on a modified measuring scale device based on the one used by Bass and Stephens (1970). The wires were deflected by using 40g weights at 14, 16, 18 and 20mm, and the deflections were read off on the ruler using a magnifying glass to the nearest quarter of a millimetre. The readings were recorded in a customised form and then transferred to a MS-Excel spreadsheet for further analysis. Means, standard deviations and distributions were calculated for all the variables. The interactions between the diameter, wire length and coil type were

assessed and compared statistically using the student's paired t-test. P values less than or equal to 0, 05 were considered significant.

The results of the study showed that there was no statistically significant difference between the load deflection rate (LDR) values of the 0.020 and 0.022 wires. The LDR of the 0.028 diameter wire showed a statistically significant difference when compared to that of the 0.020 and 0.022 wires (P<0, 01). The results also showed that increasing the length of the wire decreased the LDR. The LDR is an indication of the force required per unit deflection. A wire with a high LDR value will transmit a high force for a short span of time compared to a wire with a low LDR value which will transmit a low force over a longer time. The results of the study indicated that smaller diameter wires yielded low LDR values when compared to the 0.028 diameter wire.

The clinical relevance of this study could be pointed out to the ability of the smaller diameter wires to deliver lower forces over longer periods which might lead to an increase in rate of tooth movement.

The recommendations from this study is that clinicians need to change the mindset when using removable appliances, as the current trends in fixed orthodontics focus is on use of lighter continuous forces, by using wires with low deflection rate to increase the rate of tooth movement. This was a laboratory study; therefore clinical application should be interpreted with caution.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

A buccal canine retractor is a cantilever spring usually incorporated on a removable orthodontic appliance commonly used to retract canines that are buccally displaced. The overall shape of this spring [fig. 1 a (standard) and b (reverse) shows that it comprises a posterior arm which is bent across the line of the arch and up to the sulcus to support the coil from which the anterior arm descends to engage the canine. The difference between the standard and reverse coil springs is that the anterior and posterior arms of the reverse coil springs are bend across each other in designing the springs.

A popular design of the buccal canine retractor is usually made with 0.7 mm diameter stainless steel wire (Moyers, 1988), but it can be made with 0.5 mm diameter wire and be supported by inserting the distal leg of a 0.5mm retractor in a tube which is soldered onto a molar clasp or continues into the palatal acrylic (Houston and Isaacson, 1980).

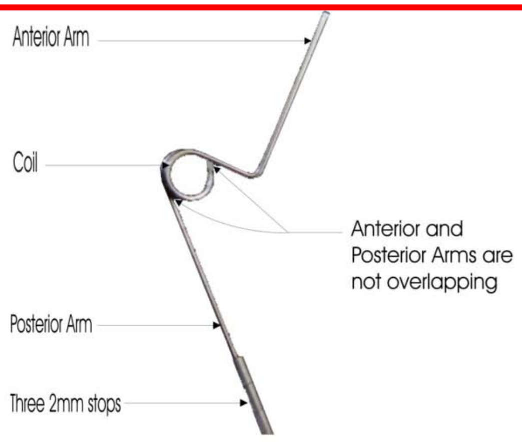

Figure A: Standard Coil Spring

(a)

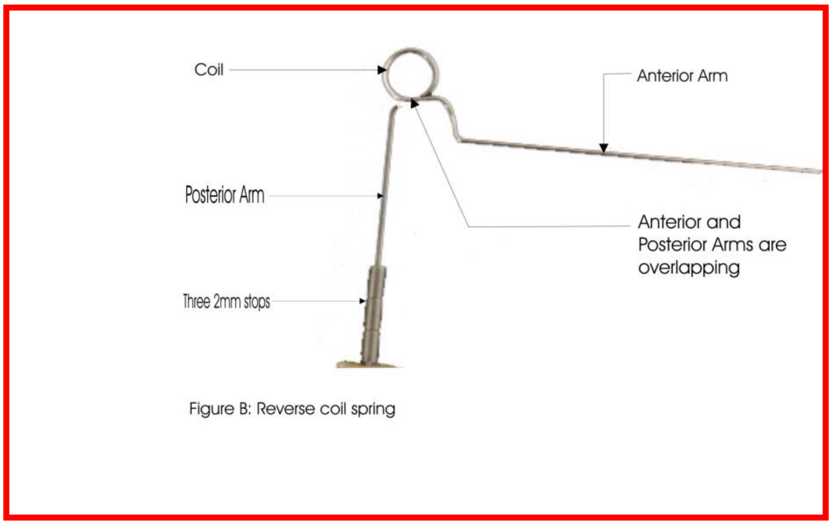

Figure B: Reverse coil spring

(b)

Figure 1-1: (a) Standard coil spring (b) Reverse coil spring

Adams and Kerr (1995) soldered a support onto the molar clasp. Their 0.7mm supported retractor had a load deflection rate (LDR) of 42g/mm, while that of the 0.6mm was 16g/mm. Different types of retractor coils (traditional/standard and the reverse coils) were demonstrated by Zietsman and Botha (2000) and the force delivery of the different types was described. They suggested a force of 55g to tilt an upper canine. Zietsman and Botha (2000) also concluded that the traditional (standard) coil was the preferred design for the supported buccal retractor.

The 0.7mm diameter wire had been the preferred size because thicker wire would not be easily damaged by the patient or easily deflected from their point of application to the tooth (Moyers, 1988). The disadvantage of using a thicker wire was the short range of action and as such the wire would need to be adjusted more frequently. Increasing the length of the retractor or using smaller diameter wires to fabricate the retractor could increase the range of action of the spring. However, increasing the length of the buccal retractor is limited by the dimensions of the dental arches and the depth of the muccobuccal fold. The buccal retractor design with an increased length may be uncomfortable to the patient and may cause traumatic ulceration if extended too far into the buccal sulcus. This problem could potentially be solved by using a wire with reduced diameter, which would allow us to bend a shorter retractor which would be springier by incorporation of a coil.

1.2 MOTIVATION FOR THE STUDY

The incidence of buccal canine impaction has been reported to be between 3, 58% (Aydin, Yilmaz and Yildirim, 2004). Although this might be very low, buccally impacted canines continue to be one of the commonly seen orthodontic problems. The use of removable appliances including the buccal canine retractor is popular among general dental practitioners who can be the first team to diagnose and manage displaced canines. The use of buccal retractor springs of smaller diameter wires without supported distal arms has not been reported in literature and also the load deflection rate (LDR) is not known.

1.3 PURPOSE OF THE STUDY

The purpose of the study was to determine the force delivery of buccal canine retractors of smaller wire diameter, namely 0.020 inch (0.51mm) and 0.022 inch (0.56mm) Unitek® wire.

1.4 OBJECTIVES OF THE STUDY

1.4.1 To determine the LDR of smaller diameter wires.
1.4.2 To assess the LDR of these wires at different wire lengths.
1.4.3 To assess the LDR of these wire for the different coil types.
1.4.4 To compare the LDR of these wires with the standard 0.028 (0.7mm) wire.

1.5 HYPOTHESES

1.5.1 Null hypothesis (Ho1)

LDR of smaller diameter wires does not differ from that of larger diameter wires

1.5.2 Null hypothesis (Ho2)

LDR of smaller diameter wires, for both the standard and reverse coil spring design should not differ significantly.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Removable orthodontic appliances

The removable orthodontic appliance has to impart orthodontic tooth movement namely tipping but cannot cause bodily movement of a tooth. The system uses mechanical forces that are applied through active elements like canine retractors and orthodontic springs, to the teeth taking into account occlussal changes as a result of growth and functional changes which play a major role in orthodontic treatment planning and outcomes of treatment. Forces are applied through the active elements of these appliances to the crowns of these teeth. The line of action of this force does not pass through the centre of resistance of the tooth and hence the tooth will tip about a fulcrum which is located in the middle third of the root (Nanda, 1996). Due to this tipping movement the crown of the tooth will move in the direction of the force whilst the apex moves to the opposite direction.

2.1.1 Active elements

An orthodontic appliance has been described to consist of active and reactive elements. The active elements provide tooth movement while the reactive elements provide anchorage by engaging teeth that will not be displaced. Some orthodontic appliances can have an element serving as active and reactive (Graber, Vanarsdall and Vig, 2005). The active elements apply the forces to the crowns of the teeth and are incorporated into the appliance system by being embedded into the acrylic base plate. Metals and rubber-like substances (form active components of headgears) are the two types of materials which are commonly used to fabricate active elements. These have different energy storing capabilities due to their different internal structure. Metals are crystalline structures with low reversible extensibility properties with a high potential to save greater energy per unit volume (Houston and Isaacson, 1980).

Types of retractors

These can be classified as palatal or buccal retractors based on the site from which they operate.

PALATAL SPRINGS

The following springs are employed on the palatal aspect to effect tooth movement namely, single cantilever spring (finger spring), double cantilever spring (Z spring), coffin spring and screws.

BUCCAL RETRACTORS

These springs are incorporated on the appliance to exert their force on the buccal aspect of the tooth. These include the canine retractor springs, canine pusher, etc. The buccal canine retractor can be supported or unsupported. The length of this spring can be increased by incorporation of the loop in a standard or reverse form.

Unsupported buccal retractor

Unsupported buccal retractor is used to move a buccally displaced canine palatally and distally. These are uncomfortable for the patient, are difficult to adjust and are unstable in the vertical direction. They are constructed from a larger diameter wire size to increase stability and this makes them much less flexible as compared to palatal springs (Houston and Isaacson, 1980).

Supported buccal retractor

Supported buccal retractor is identical in design with the unsupported buccal retractor described above but it is made of a smaller diameter wire supported in a tubing. The anterior leg (shorter free end) is made more flexible than the standard buccal retractor and this is achieved by reducing the wire diameter. The tubing that is used in the posterior leg provides excellent vertical stability making it more flexible mesiodistally than it is vertically (Zietsman and Du Toit, 2002).

Standard loop buccal retractor

This retractor is used more commonly and also the loop must be made as high as possible to increase its flexibility (Houston and Isaacson, 1980).

Reverse loop buccal retractor

This retractor is used commonly in cases where the sulcus is shallow as in the lower arch. The vertical loop must be made as high as possible so as to increase the flexibility of the retractor. The disadvantage of the spring is that it is stiff in the horizontal plane and unstable vertically and as such is not used commonly (Houston and Isaacson, 1980).

2.1.2 Retentive elements

Baseplate

The body of a removable appliance consist mainly of a base plate which is made of acrylic resins. The baseplate acts as a foundation into which active and retentive components are imbedded. It also contributes to the anchorage during the course of active tooth movement. The baseplate contributes to preservation of anchorage in two ways. Firstly teeth can contribute to the anchorage through the close fit of the acrylic around their necks. Secondly anchorage can be achieved through contact of the appliance with the mucosa of the vault of the palate. Baseplates act as distributors of reaction forces to the anchorage areas. Biting planes can also be incorporated into the baseplate (Houston and Isaacson, 1980).

Baseplates must be fabricated in such a way that they are not too thick and bulky and hence uncomfortable for the patient resulting in difficulties in speech and eating. A single thickness of pink wax can be used as a guideline for the thickness of the baseplate with the wire elements stabilized in it. To achieve comfort for the patient the posterior edge of the baseplate must be trimmed forward in the centre line and be moulded round the distal aspect of the last tooth. Undercuts on the plaster models should always be blocked out before construction of the appliance for ease of insertion and removal of the appliance (Adams and Kerr, 1995). Proffit and Fields (2007) mentioned that a common error often practiced was not trimming the baseplate along the path of movement of the tooth. Baseplate material must also be trimmed away to complete activation of the spring. To facilitate anchorage and to prevent movement of the appliance the baseplate material must be kept intact and not removed around the clasp; this will prevent movement of the anchor tooth and enhance retention of the appliance (Adams and Kerr, 1995).

The baseplate is fabricated on the model after completion of the wirework and boxing in of the springs. Conventionally heat – cured acrylic resins have been used but in recent years there has been a great increase in the use of cold cure acrylic. With the cold cure technique the active and retentive components are secured in place with a dab of wax applied on the buccal side of the teeth. After application of the separating medium the baseplate is built up by the addition alternately of polymer powder and monomer liquid respectively (Adams and Kerr, 1995).

Adams' clasps

These utilize the mesiobuccal and distobuccal undercuts of a tooth for retention. It consists of a bridge that is constructed so that it is shorter than the distance between the two undercuts. It consists of arrowheads that are about 3mm in length adjusted to follow the gingival contour and lying at about 45 degrees to the occlussal plane. The clasp must be bend so that the bridge is parallel to the the occlussal plane and clear from the tooth when it is in position. The wire should conform closely to the teeth where it passes the contact areas and must adapt well in the palatal embrasure. The wire must be held 1mm clear of the palate so as to allow free flow of the acrylic of the baseplate.

An incisor clasp is a modification of an Adams' clasp providing retention anteriorly by spanning both incisors. C-clasps are commonly used on deciduous teeth.

Labial bows are useful in providing retention anteriorly especially in cases where incisors are proclined (Adams and Kerr, 1995).

2.1.3 Anchorage

Anchorage is defined as the resistance to reaction forces (Proffit and Fields, 2007). Anchorage can be provided by other teeth, by the palate, head or neck (via extra – oral force) or implants in bone. It is important to take into account the reciprocal effects when planning orthodontic therapy. Planning for anchorage will help in maximizing the tooth movement that is desired while minimizing undesirable side effects.

The resistance to tooth movement (anchorage values) can be defined as a function of its root surface area which is the same as its periodontal ligament area. The greater the root surface area, the greater the area over which a force can be distributed and vice versa (Proffit and Fields, 2007). Anchorage can be attained generally by intraoral and extraoral means. Intraorally retentive components of the removable appliance discussed earlier can be used i.e Adam's clasp and the baseplate. Extraorally headgears can be used in combination with removable appliances (Graber, Vanarsdall and Vig, 2005). There are other means of obtaining anchorage that are beyond methods used with removable appliances.

Types of anchorage

Reinforced anchorage

Anchorage can be reinforced by adding more resistance units e.g. more teeth or extraoral structures in the anchorage units. This will increase the total surface area of the PDL and hence the reaction force is distributed over a larger area (Moyers, 1988).

Stationary anchorage

Applying pressure to the crowns of the teeth that are used as anchorage units will cause tilting of those teeth. Interceptive measures to prevent tilting of the anchorage unit can be applied. These will assist in distributing the pressure applied to the teeth uniformly over the total root surface area and as such reducing the pressure per unit of root area (Adams and Kerr; 1995). This type of anchorage control requires use of light forces. In stationary anchorage a tooth that resist bodily movement provide greater anchorage than the one resisting tipping force (Bhalajhi, 2007).

Cortical anchorage

Profit and Fields (2007) states that cortical bone is more resistant to resorption when compared to medullary bone and as such tooth movement is slowed when a root contact it. The resistance provided by cortical bone can be used to attain anchorage and this manner of deriving anchorage is termed cortical anchorage.

2.2 Biomechanics of tooth movement

Orthodontic appliances deliver forces that can be measured and that can cause displacement of teeth within the sockets (Graber, Vanarsdall and Vig, 2005). Most orthodontic appliances including the buccal retractor deliver a complicated set of forces and moments.

Force

Proffit and Fields (2007) defined a force as a load applied to an object that will tend to move it to a different position in space. It is defined in units of Newton's (mass times the acceleration of gravity) but is usually measured in weight units of grams or ounces.

A force is a vector defined by characteristics of a vector. Vectors are characterised by having both magnitude and direction (Nanda, 1996). The magnitude of the vector represents its size and the application point describes its direction. Activation of the buccal retractor is a means of producing an orthodontic force. Force that is required for basic tooth movement for a single rooted tooth ranges from 25-40g. The force that is applied by the spring is directly proportional to its deflection provided the wire remains within its elastic range. Thus as the tooth moves the force decreases but if the force remains within a range of 25-40g it will still be sufficient to produce tooth movement (Houston and Isaacson, 1980).

A spring activation of 3mm is sufficient to attain forces within the range of 25- 40g. The patient is more likely to insert the spring incorrectly with larger deflections. Smaller deflections will lead to rapid dropping of the force as the tooth moves causing the need for the spring to be reactivated frequently. Palatal springs fabricated with a 0.5mm diameter wire have a load-deflection ratio of about 15g/mm. Thus activating such a spring one third of a tooth width (3mm) will generate a force within the optimal range (Houston and Isaacson, 1980).

Centre of resistance (CRs)

Proffit and Fields (2007) defined CRs as a point at which resistance to movement could be concentrated for mathematical analysis. Nanda (1996) defined CRs as analogy to the centre of mass of an object. Centre of mass is the point through which an applied force must pass for a free object to move linearly without rotation and hence it can be called the balanced point. The CRs is analogous to centre of mass for restrained bodies like teeth that are held within the periodontal ligament space (Nanda, 1996). CRs can be described in each plane of space and is dependent on root length and morphology, number of roots and the level of alveolar bone support. CRs is determined by the nature of external constraints. The CRs for a single rooted tooth with a parabolic shape can be determined by multiplying the distance from the alveolar crest to the apex by 0.33 (Graber, Vanarsdall and Vig, 2005). Since the CRs coincides with the centroid, which in the case of the canine will be the geometric centre of the part of root between alveolar crest and apex.

It is not easy to locate the CRs of a tooth but a number of analytical studies have proven that the CRs of a single rooted tooth with normal alveolar bone level to be about one-fourth to one-third of the distance from the cemento-enamel junction to the root apex (Tanne, Koening and Burstone, 1988). A force placed near CRs of root should produce pure translation (Graber, Vanarsdall and Vig, 2005).

Moyers (1988) illustrated the relationship between CRs and centre of rotation for a single tooth (Fig 2-1). A general equation was developed by Nagerl *et al.*, (1991) stated that the product of the distance from point of force application to the CRs and the distance from CRs to centre of rotation equals a constant. These researchers further reported that this equation will make it possible to determine the centre of rotation for teeth with the same morphologic characteristics. Proffit and Fields (2007) also confirmed that the product of these distances will remain a constant irrespective of the point of force application.

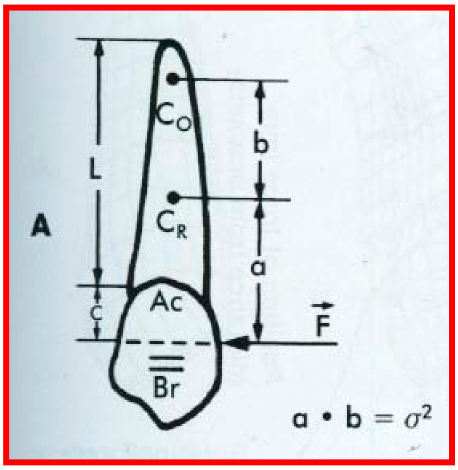

Figure 2-1: Relationship between centre of resistance (Cr) and centre of rotation (Co) (Moyers 1988)

It is important to have an apparent awareness of CRs of a tooth in clinical orthodontic practice when selecting and activating an orthodontic appliance. This is important as the type of tooth movement expressed is determined by the relationship of the force system acting on the tooth and Cr (Nanda, 1996).

Centre of rotation (CRt)

Proffit and Fields (2007) defined CRt as the point around which rotation occurs when moving an object. Yettram, Wright and Houston (1977) defined CRt as a fixed point about which a body undergoes pure rotation at each instant in time. Yettram and co-workers (1977) investigated the CRt of the maxillary central incisor by means of the finite element system. They found that a relationship existed between the CRt of a tooth and the distribution of the resultant remodelling of alveolar bone and periodontal ligament. The CRt of a tooth has been reported to be determined by the moment to force ratio and not the actual force magnitude (Proffit and Fields, 2007; Christiansen and Burstone, 1969; Yettram, Wright and Houston 1977).

Burstone and Pryputniewicz (1980) reported that a relationship existed between M/F ratio and the CRt. They proved that at a M/F ratio of zero, the CRt would be slightly apical to the centroid but as the values of the M/F ratio become more negative, the CRt would be moved apically. Their experimental results however showed that location of the CRt was less sensitive to M/F ratio changes.

Moment

A moment is defined as the product of the force and the perpendicular distance from the point of force application to the centre of resistance (Proffit and Fields, 2007). If the line of action of the applied force does not pass through the centre of resistance, a moment of the force is generated. Nanda (1996) defined the moment of a force as a tendency of a force to cause rotation. The moment has magnitude and direction which is determined by following the line of action around the center of resistance towards point of origin (Nanda, 1996). The unit used to measure the moment of a force is in gram millimetres or newton millimetres (Nanda, 1996). The effects of moment of a force are not recognized in clinical orthodontics but it is important to recognize this in developing an effective and efficient appliance design. This moment of a force will tend to cause rotation of the object around CRs.

Moment to force (M/F) ratio

M/F ratio is a phenomenon that is used to explain the type of tooth movement that will be expressed when a force is applied on the tooth surface. The primary determinant of orthodontic tooth movement has been shown to be the M/F ratio at the point of application rather than the absolute force (Burstone, 1994). Tanne, Koening and Burstone (1988) used the finite element method to illustrate the relationship between M/F ratio and CRt. They found that small changes in M/F ratios produced clinically significant changes in CRt, thus indicating that the CRt was very sensitive to changes in the M/F ratio. Moyers (1988) stated that different types of tooth movements can be produced by altering the M/F ratio.

Nanda (1996) stated that the M/F ratio of the applied force determined the type of tooth movement at the centre of rotation. This statement was backed by a number of researchers (Burston and Pryputniewicz, 1980; Christiansen and Burstone, 1969; Tanne, Koening and Burstone, 1988).

2.3 Theories of tooth movement

Proffit and Fields (2007) defines two major theories of significance in tooth movement namely, the pressure tension theory and pizoelectric theory.

2.3.1 Pizoelectric theory

Farrar (1876) was the first to suggest that bone bending maybe a possible mechanism for bringing about tooth movement. Pizoelectricity is defined as an occurrence that is observed in many crystalline structures whereby a deformation of the crystalline structure produces a flow of electric current due to displacement of electrons from one part of the crystal lattice to another (Proffit and Fields, 2007).

Bone mineral has been reported to be crystal structure possessing pizoelectric properties. One of the characteristics of a piezoelectrical signal is that it has a quick decay rate. When a force is applied to a crystal structure a piezoelectric signal is generated and quickly dissipates to zero even though the force is maintained. The other unusual characteristic of crystal structures is the production of signal equivalent in magnitude but in opposite direction when force is released (Proffit and Fields, 2007).

2.3.2 Pressure – tension theory

Oppenheim (1911) was the first person to study the tissue changes in the bone related to orthodontic tooth movement. Schwarz (1932) is cited as the first author of the pressure-tension theory in the literature. It was stated in this theory that when a tooth was subjected to an orthodontic force it resulted in areas of pressure and tension. The area of the periodontium in the direction of tooth movement was under pressure while the area that was opposite tooth movement was under tension. According to the theory the areas of pressure showed bone resorption while areas of tension showed bone deposition (Schwarz, 1932).

This is the theory of tooth movement that is controlled by changes in chemical environment rather than electrical signals that activate cellular differentiation and ultimately tooth movement. Force application on the tooth will cause the tooth to change its position within periodontal ligament (PDL) space, compressing the ligament in some areas and stretching it in others (Proffit and Fields, 2007).

This will alter the blood flow within the (PDL), decreasing the blood flow in compressed areas and maintaining or increasing it in areas under tension. Altering blood flow in the PDL will lead to changes in the chemical environment. These changes in chemical environment can either act directly or stimulate secondary messengers to activate differentiation and activity of cells which would bring about remodelling at the bone and hence tooth movement within the socket.

This theory can summarized as:

Force application
↓
Blood flow changes due to pressure changes in PDL
↓
Activate release of chemical messenger
↓
Activation of cells

2.3.2 Physiologic response to applied force

Type of cellular response that is elicited is dependent on the force magnitude (Reitan, 1951; Melsen, 1999). Application of light prolonged force to a tooth will move the teeth within its socket and lead to partial compression of PDL on one side and tension on the other. Within 3-5 seconds blood vessels within the PDL will be partially compressed on the pressure side, dilated on the tension side and the distortion of PDL fibres and cells occur. Within minutes alterations in blood flow lead to changes in oxygen tension which activate certain chemical agents e.g. prostaglandins and cytokines. Prostaglandin and cytokines are important mediators of cellular differentiation (Proffit and Fields, 2007).

Through signalling and other transduction pathways, mediators are produced that activate several types of cells (Melsen, 1999). Also cells of the PDL are activated by mechanical stimulation and release specific mediators which elicit specific cellular responses. (Dereka, Markopoulou and Vrotsos, 2006; Terai, 1999). Within 4 hours enzyme levels change due to changes in cellular activity elicited by chemical messengers. Increased levels of cyclic adenosine monophosphate (cAMP) become detected. It has been shown that cAMP act as a second messenger for cellular differentiation of mesenchymal cells into osteoblastic or osteoclastic cells within the periodontum (Davidovitch *et al.*, 1988).

Activated osteocytes produce the following factors; bone morphogenetic proteins (2, 6 and 9), platelet derived growth factors. These factors stimulate the precursors in PDL to differentiate into osteoblasts (Dereka, Markopoulou and Vrotsos*,* 2006). Osteocytes also respond to strain in vivo by the production of cytokines, nitrous oxide (NO), prostaglandins and tumour necrosis factor-alfa (Westbroek, 2000). The cytokines produced by osteocytes activate osteoclast precursors in the PDL at the resorption side, while NO inhibits the activity of osteoclast at the opposition side (Yoo, Warita and Soma, 2004).

At the resorption side, soluble factors such as colony-stimulating factor, receptors activator of nuclear factor kappa B ligand (RANKL), osteoprotegerin and bone morphogenetic proteins regulate osteoclasts differentiation (Zhao *et al.,* 2002; Kurata *et al.,* 2006). These factors are produced by osteocytes present in alveolar bone and by osteoblasts and fibroblasts present in the PDL.

Before actual resorption of bone can occur, osteoblasts have to degrade the non-mineralized layer of the osteoid. Only after degradation of this layer can differentiated osteoclast attach to the bone surface (Birkesdal-Hansen, 1993). This attachment is mediated by specific intergrins-alfa and beta-3 and is stimulated by osteopontin (OPN) produced by osteoblasts and osteocytes (Gay and Weber, 2000).

Bone formation at the apposition side of the tooth is a combination of extracellular matrix synthesis and mineralization. *In vitro* studies showed that loading of PDL cells results in an increased production of alkaline phosphatase, osteocalcin and other non-collagenous matrix proteins (Yang *et al.,* 2006). These factors might stimulate precursors in PDL to differentiate into osteoblasts, leading to subsequent bone deposition. After mechanical stimulation in vitro, osteoblasts produce NO, which is a mediator of bone formation (Owan, 1997).

2.4 Types of tooth movement

Tooth movement is a complex biologic response of the periodontium that is initiated by application of a force. This leads to release of active biologic substances that ultimately activate cells which cause remodelling of the tooth socket and tooth movement (Proffit and Fields, 2007).

Type of tooth movement in clinical orthodontics can be described by the moment to force ratio. Each type of basic tooth movement is as a result of a variation of the applied moment and force (Nanda, 1996). The basic types of tooth movement namely tipping, translation, rotation and root movement have been described by assessing the M/F ratios required for the particular tooth movement (Nanda, 1996). It is important to note that removable appliances can only cause tipping movement which is the relevant type of tooth movement for this current study.

Tipping

This type of tooth movement is achieved throgh greater movement of the crown of the tooth than the root (Nanda, 1996). Proffit and Fields (2007) stated that only one half of the total periodontal ligament area is actually loaded when this movement is expressed. Pressure is concentrated at the alveolar crest and at the root apex and is extensively high in relation to the force that is applied to the crown thus due to this unequal distribution of the stresses along the periodontium, the forces applied must be kept quite low, and a force magnitude of 35-60gm for tipping movement has been proposed (Proffit and Fields, 2007).

Nanda (1996) classified tipping movement on the basis of location of the centre of rotation into controlled and uncontrolled tipping. Uncontrolled is defined as tipping with centre of rotation between centre of resistance and apex. It is caused by a force acting in a horizontal dimension and causing the crown and root to move in opposite directions. This generates a nonuniform stress pattern of the periodontium with maximum stresses created at the apex and crown. The M/F ratio for this type of tooth movement is 0:1 to approximately 5:1 for average root lengths and alveolar bone height (Andersen *et al.*, 1991; Smith and Burstone, 1984).

Controlled tipping is achieved by application of a force to move the crown and application of a moment to control the position of the root apex. The centre of rotation for this type of tooth movement is located at the root apex.

The stress at the root apex is minimal keeping the apex stationary but is highly concentrated at the cervical area which allows timely tooth movement (Andersen *et al*., 1991; Smith and Burstone, 1984). The M/F ratio of 7:1 is necessary for this type of tooth movement (Nanda, 1996).

Summary

The supported buccal retractor is preferred choice of retractor than the unsupported retractor due to its better stability in the mouth as cited in literature (Zietsman and Du Toit, 2002). Force level that ranges from 25-40g is needed to initiate tooth movement of a single rooted tooth. A deflection of 3mm of the retractor is sufficient to attain forces within the range of 25-40g (Houston and Isaacson, 1980). The force that is applied by a retractor is directly proportional to its deflection provided the wire remains within its elastic range (Isaacson, Muir and Reed, 2002). The 0.028 inch diameter stainless steel wire has been used routinely to fabricate this retractor. Therefore the purpose of this current study is to investigate the LDR of small diameter wires (0.020 inch and 0.022 inch).

CHAPTER 3

MATERIALS AND METHODS

3.1 Sample size

The Unitek 0.020 inch (0.51mm), 0.022 inch (0.56mm) and 0.028 inch (0.7mm) stainless steel wires were used for this study. Two types of buccal retractors namely the standard coiled and reverse coiled buccal retractors were fabricated. Ten of each of the two types of the buccal retractors were fabricated using the 0.020 inch, 0.022 inch and 0.028 inch diameter wires. These were made at 20, 18, 16 and 14mm lengths respectively. The 0.028 inch wire was used as a control sample (Table 3-1 and Table 3-2).

Table 3-1: Distribution by standard coil type and spring length of the study (n=120).

	SPRING LENGTH						
COIL TYPE Standard(S)	WIRE DIAMETER	n=120	14 mm	16 mm	18 mm	20 mm	Total
		0.020	10	10	10	10	40
		0.022	10	10	10	10	40
		0.028	10	10	10	10	40
		TOTAL	30	30	30	30	120

Table 3-2: Distribution by reverse coil type and spring length of the study (n=120).

	SPRING LENGTH						
COIL TYPE Reverse coil (RS)	WIRE DIAMETER	n=120	14 mm	16 mm	18 mm	20 mm	Total
		0.020	10	10	10	10	40
		0.022	10	10	10	10	40
		0.028	10	10	10	10	40
		TOTAL	30	30	30	30	120

3.2 Experimental procedure

Using a Unitek® 403 loop forming pliers (Figure 3-1) 10 standard-coiled (SC) and 10 reverse-coiled(RC) buccal retractors (Figure 3-2 and Fig 3-3 respectively) were fabricated by hand from 0.020, 0.022 and 0.028 inch thick stainless steel wires.

Figure 3-1 Unitek 403 loop forming plier

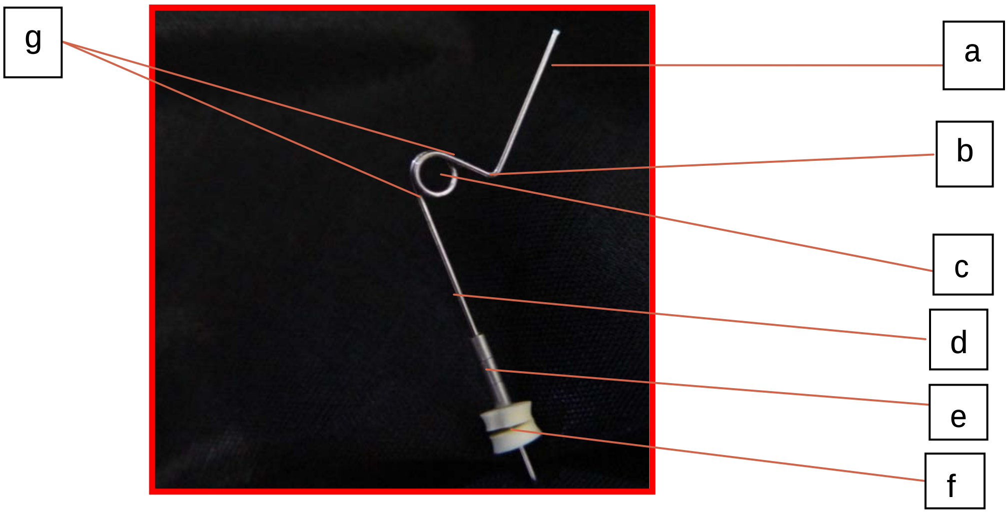

Figure 3-2 Standard coiled buccal retractor: a-anterior leg; b-90 degrees bend on anterior leg; c-coil; d- posterior leg; e-three 2mm crimp tubes on posterior leg; f-rubber stops at 20mm mark; g- 45 degree bend between anterior and posterior leg

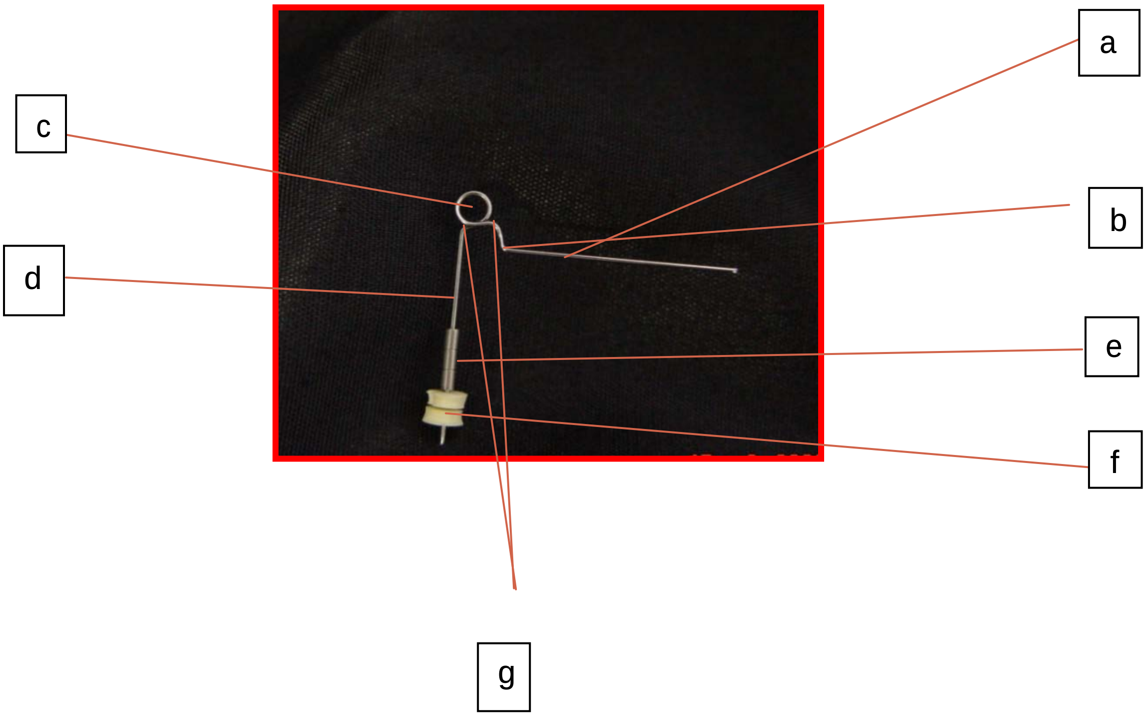

Figure 3-3 Reverse coiled buccal retractor: a- anterior leg; b-90 degrees bend on anterior leg; c-reverse coil; d-posterior leg; e- three 2mm crimp tubes; f- rubber stops at 20mm mark; g-45 degrees bend between anterior and posterior legs

The retractors consisted of two legs, anterior leg (20mm) and posterior leg (30mm) in length and bent at 45 degrees to each other a, d, g respectively in Fig 3-2 and 3-3.

The measurements of the retractor legs were done with the coil pushed against the one end of the dial calliper to obtain the desired length. The one end of both the anterior and posterior legs was marked by using a file and the wire was cut at that point. Similarly, using the dial calliper, another mark on the posterior leg of the coil was made at 20mm to position the 20mm rubber stops. Two rubber stops (f) in Fig 3-2 and 3-3 were used for better stability at that point. Three crimp tubes each 2mm in length were inserted onto the posterior leg above the rubber stop which was at the 20mm file mark. The crimp tubes (e) in Fig 3-2 and 3-3 were used to mark the 18, 16 and 14mm lengths in the posterior leg. The anterior leg was bent about 2mm from the coil at 90 degrees (b) in Fig 3-2 and 3-3 so that the retractor would be positioned properly in the gravity scale device.

A modified gravity scale device (Fig 3-4) based on Bass and Stephens (1970) was designed for the experiment and used to measure the force delivery of each of the fabricated buccal retractors.

The original Bass and Stephen (1970) gravity scale consisted of clamping devices that were used to hold the one leg of the orthodontic spring with the ruler on the opposite side for measuring the deflections. Our modified gravity scale (Fig. 3-4) consisted of a clamping device (e) which was used to hold the anterior leg of the retractor. The clamping devices were designed such that they could be opened and closed using a screw (c) and rotated at 180 degrees. The ruler (a) was used to measure the distance at which the wire was deflected. It was designed in such a way that it could be rotated at 180 degrees so that the posterior leg of the retractor (d) in

Fig 3-2 and 3-3 was always orientated at 90 degrees to the ruler after being inserted onto the gravity scale.

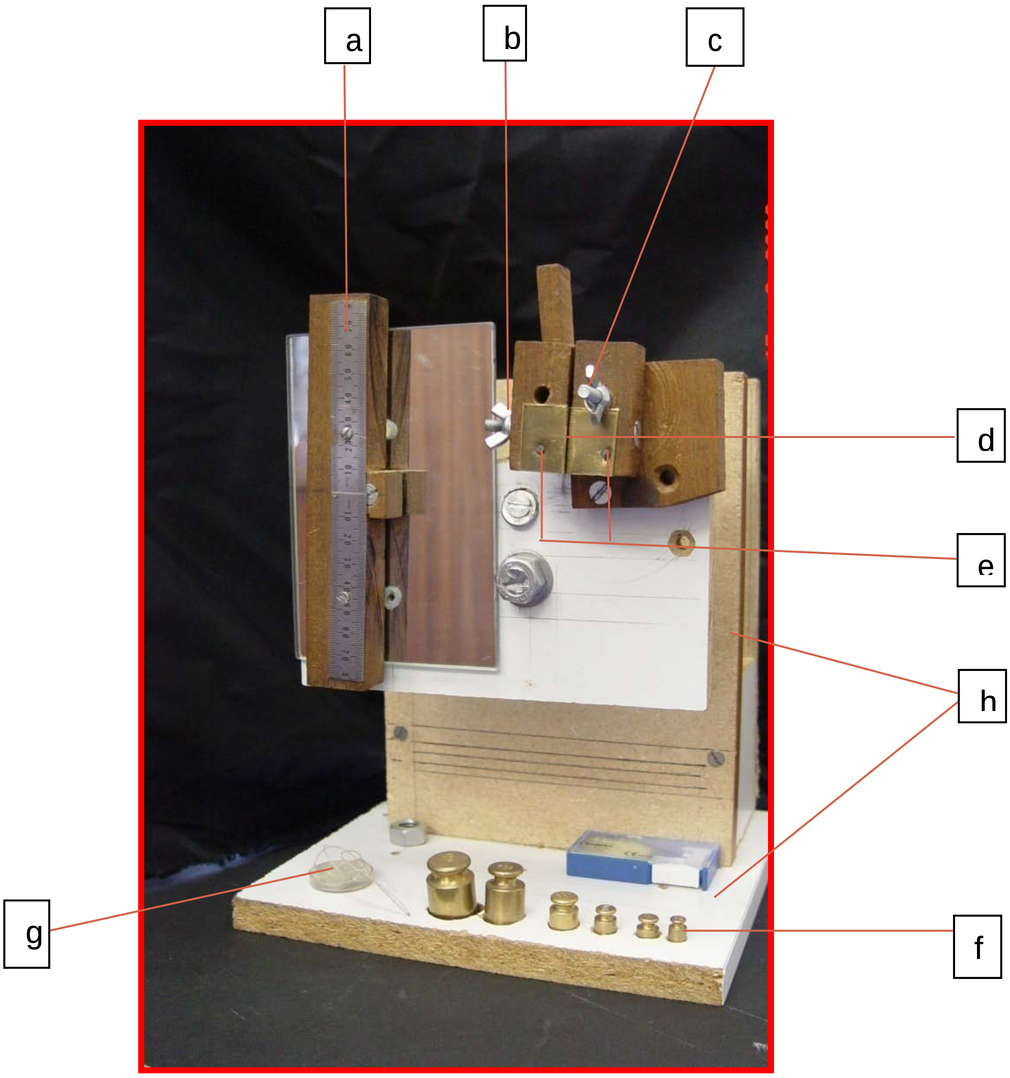

Figure 3-4 Modified Gravity Scale based on Bass and Stephens gravity scale device: a- mm ruler; b- screw 1; c- screw 2; d- space for inserting wire between clamping devices; e- clamping devices; f- weights; g- basket with a hanging string; h- supporting stand

The deflections were read in mm along the ruler. The basket (g) used to carry the weights (f) was attached to a string which was used for hanging on the posterior leg of the retractor. The basket was first hanged on the retractor without the weight on it and the ruler was then adjusted so that it was at 90 degrees with the wire and the basket. The basket was hanged on the posterior leg of the retractor at a specific distance i.e 20, 18, 16 or 14mm distance using the crimp tubes for the distances. The ruler of the gravity scale was adjusted by moving it so that the posterior leg of the retractor with the basket hanging was at 90 degrees and aligned to zero point on the ruler before the weights were loaded. This was done to cancel out the weight of the basket.

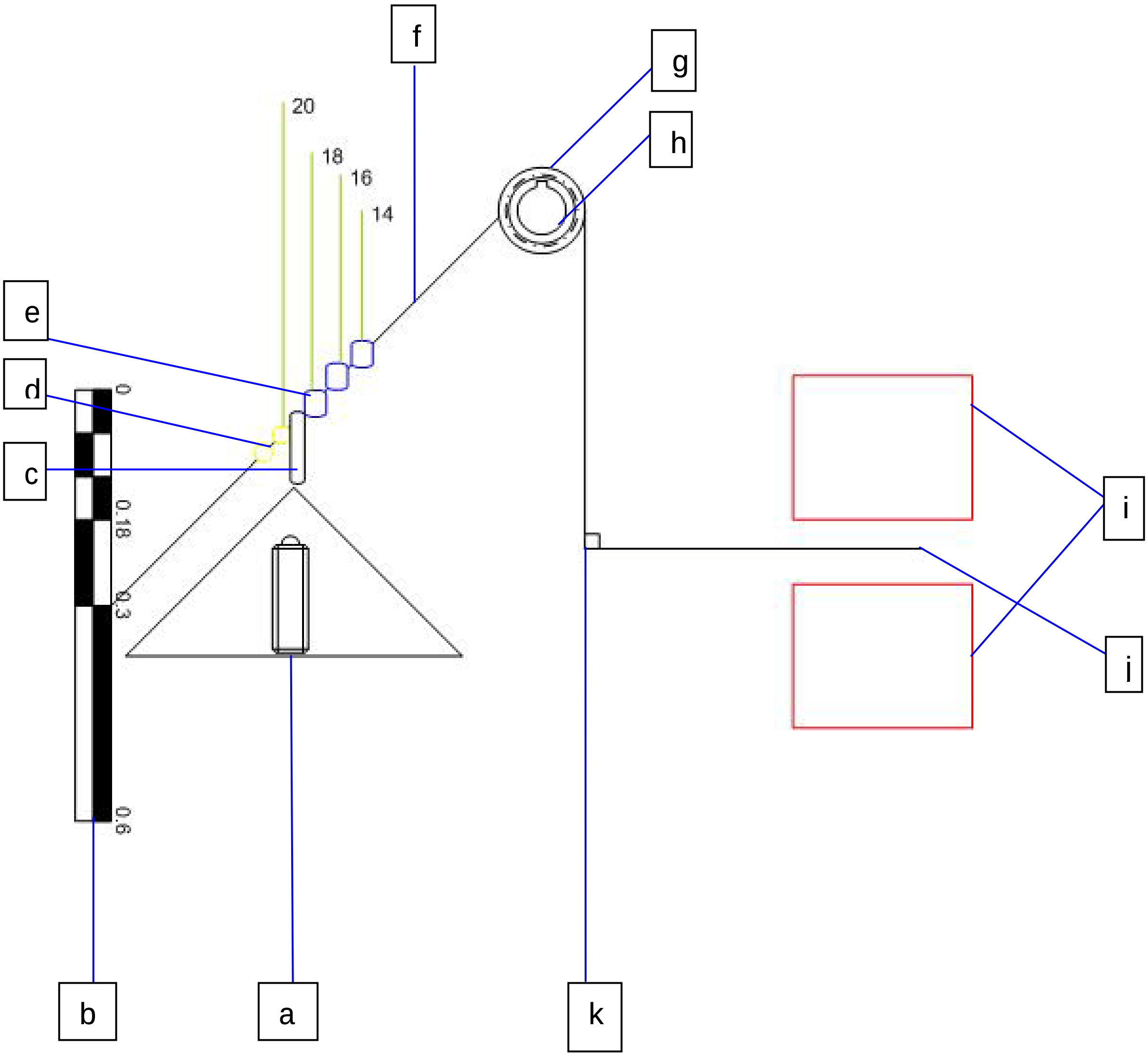

Fig. 3-5 Graphic representation of experiment method: a- basket with weight; b- ruler of gravity scale device; c- string of basket hanging from posterior leg; d- two rubber stops; e- three 2mm crimpable tubes; f- posterior leg; g- coil of retractor; h- screw 1; i- clamping device of gravity scale; j- anterior leg inserted in space between clamping device; k- 90 degrees bend on anterior leg

Fig 3-5 is the graphic representation of the experiment. The anterior leg (j) of the retractor was clamped into the device so that the top part of the coil (g) lied exactly over the centre of the screw 1 (h) and that it was exactly at right angles to the clamping device (i).

The basket (a) was hooked against the rubber stop i.e. the 20mm retractor and the crimp tubes were moved tightly up against the string (c). The posterior leg (f) of the retractor was lined up with the zero point on the metal ruler (b) on the gravity scale device with the aid of a mirror image and a magnifying glass. The 30mm mark on the posterior leg of the retractor was orientated so that it was at right angles to the edge of the ruler once lined up correctly. The ruler (b) was designed in such a way that it could be rotated 180 degrees so that it could be orientated at 90 degrees to the posterior leg of the retractor. A 20g weight was placed in the basket (a) and the wire as such was deflected. The deflection was read off on the ruler using the magnifying glass to the nearest quarter of a millimetre. Each measurement was repeated three times at each length (20, 18, 16, 14 mm respectively) and the three values were entered into a spreadsheet for analysis.

The procedure was repeated with the 40g weight placed in the basket and the deflections were read from the ruler as described above. To calibrate the machine and the researcher the measurements were done using the 40g and 20g weights to check the level of the LDR. It was expected that the deflections at 40g would be double those values at 20g or within that range. The 20g weights were just used as a reference for the experiment and were not used to calculate the LDR. However the experiment measurements were recorded with the 40g weight. The readings were recorded in a customised form and then transferred in MS-Excel spreadsheet for further analysis (Addendum A).

3.3 Statistical analysis

The statistical analysis was carried out by a senior statistician at the Unit of Biostatistics of the Medical Research Council (MRC) in Pretoria. Means, standard deviations and the distributions were calculated for all the variables. The interactions between diameter (0.020, 0.022 and 0.028), wire length (14, 16, 18 and 20mm) and coil type (reverse and standard coils) were assessed and compared, and statistical significance for these interactions was determined using the Student’s paired t-tests. Testing was done at the 0.05 level of significance.

CHAPTER 4

RESULTS

Table 4.1 depicts the means, standard deviations of LDR for the SC and RC wires at different diameters. A total of 240 measurements of LDR at 40g were recorded for both SC and RC. Statistically significant differences were found between the LDR means of 0.020 inch wire and 0,022 and 0.028 as well as 0.022 and 0.028 with P- values less than 0.05, 0.01 and 0,01 respectively (Table 4.2)

Table 4.1 LDR (at 40g) distributions of standard and reverse coil wires

Diameter (Inch)	N	MEAN	SD
0.020	80	8.53	2.08
0.022	80	9.36	2.68
0.028	80	28.30	5.85
TOTAL	240	15.40	9.44

Table 4.2 T-test for comparison between wire diameter LDR

Interactions (diameter)	P-values
0.020 vs. 0.022	<0.05
0.020 vs. 0.028	<0.01
0.020 vs. 0.028	<0.01

Table 4.3 LDR distributions BY coil type

Coil type	N	Mean	SD	P – Value
RC	120	14.13	8.22	< 0.01
SC	120	16.66	11.29	
Total	240	15.40	9.94	

RC=Reverse coil, SC= Standard coil

There were 120 measurements recorded in each type of coil with a total of 240 at LDR 40g.There was statistically significant difference between the means of the LDR at 40g for the two coil types (P value is less than 0.01 as indicated in table 4.3).

Table 4.4 Means, standard deviations and distributions for spring length

Spring Length	N (LDR 40g)	Mean (LDR 40g)	SD (LDR 40g)
14	60	19.55	10.92
16	60	16.33	9.99
18	60	13.96	9.40
20	60	11.75	7.66
TOTAL	240	15.40	9.94

Table 4.5 T-test for interactions for spring length

Interactions (Spring length)	P-values
14 vs. 16	< 0.05
14 vs. 18	< 0.05
14 vs. 20	< 0.0001
16 vs. 18	< 0.05
16 vs. 20	< 0.05
18 vs. 20	<0.05

There were 60 measurements at 14, 16, 18 and 20 mm respectively at LDR 40g with a total of 240. There was a high statistically significant difference between 14mm and 20mm length wire $P < 0.0001$. Statistically significant differences were also found with all were length interactions as shown in table 4.5 above.

Table 4.6 T-test for the interactions of the coil type and diameter

Interactions (Coil type vs. Diameter)	P – values
Type 1 vs. type 2 for 0.020	P=0.3
Type 1 vs. type 2 for 0.022	P=0.3
Type 1 vs. type 2 for 0.028	P<0.0001

There was no statistically significant difference between the interaction of coil type and for 0.020 and 0.022 diameters wires for both the standard and double reverse coil types (P-value=0.3). There was a statistically significant difference between the standard and double reverse coils for 0.028 diameter wires (P<0.0001) as indicated in table 4.6. Fig 4.1 is graphic illustration of the experimental results. The LDR for 0.028 diameter wires was higher as compared to that of the 0.022 and 0.020 diameter wires for both SC and RC. There was not much difference in the LDR of both the 0.022 and 0.020 diameter wires for both SC and RC.

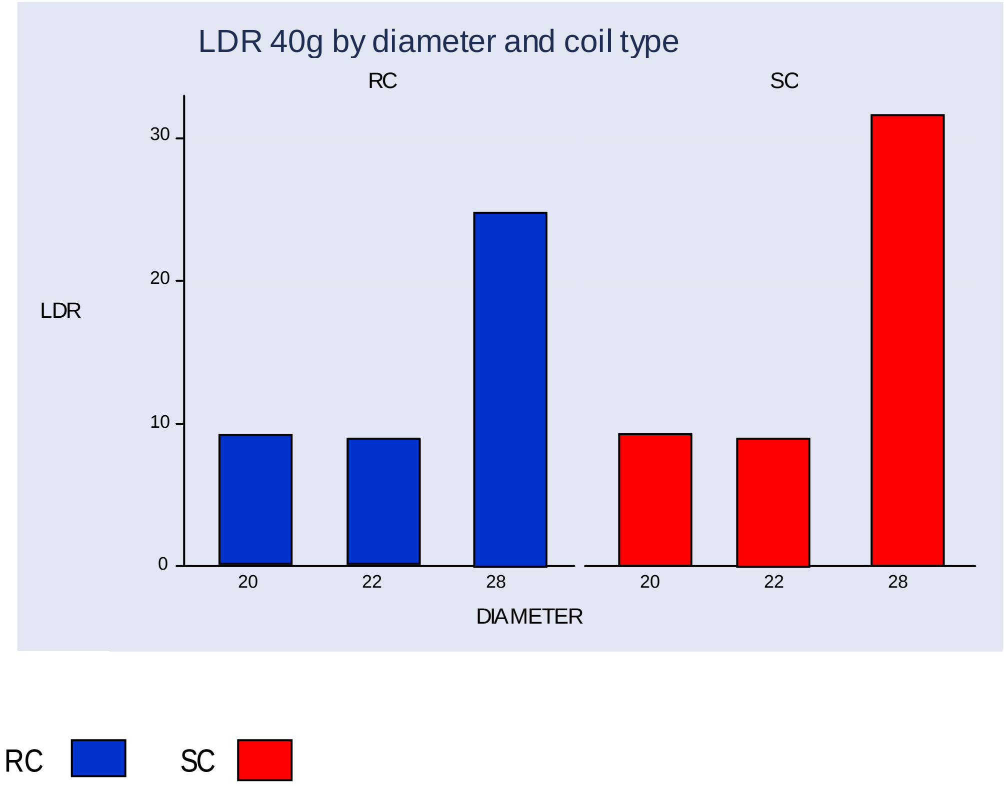

Figure 4.1 LDR 40g by diameter and coil type

Table 4.7 T-test of the interaction for coil type and spring length

Interactions (Coil type and spring length)	P –values
SC vs. RC springs at 14mm	<0.001
SC vs. RC springs at 16mm	<0.001
SC vs. RC springs at 18mm	<0.001
SC vs. RC springs at 20mm	<0.001

There were significant statistical differences between the two coil types at different lengths (P<0.001) as indicated in table 4.7. There is an inverse relationship between spring length and LDR as shown by the graphic bar representation (fig. 4.2).

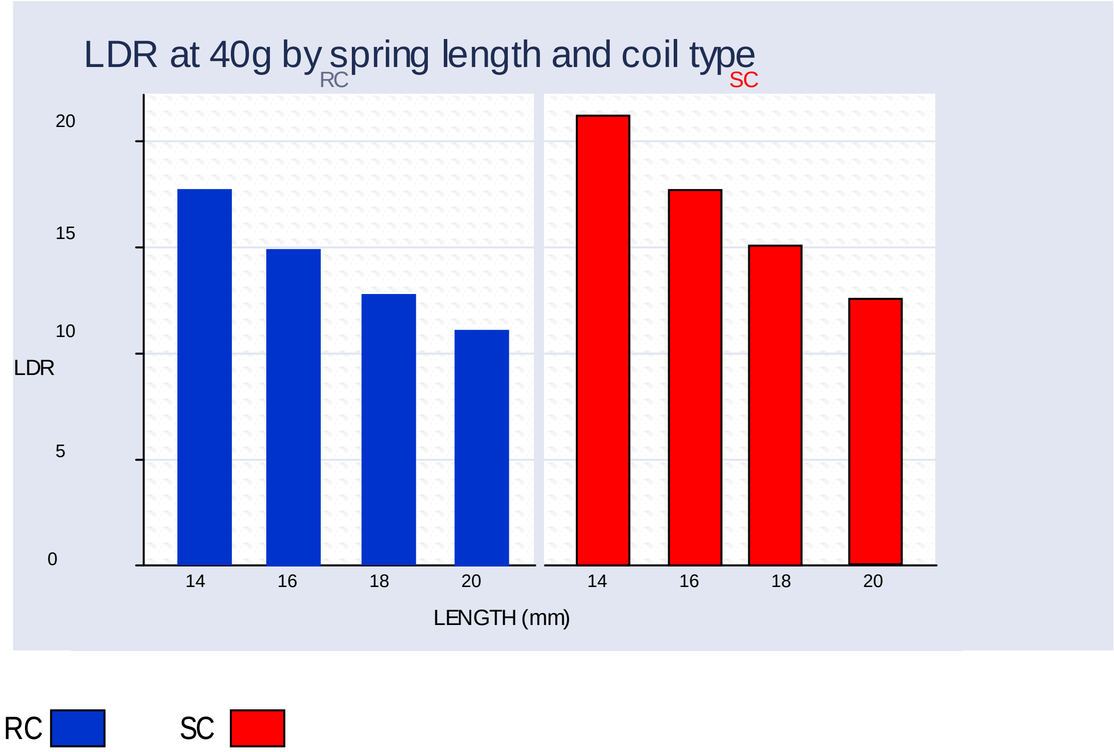

Figure 4.2 LDR at 40g by spring length and coil type

Fig 4.2 was a graphic illustration of the experiment results. As illustrated in the graph there was an inverse relationship between spring length and LDR at 40g for SC and RC. The LDR was higher for the SC as compared to the RC.

Table 4.8 T- test for the interactions for spring length and diameter

Interactions (Spring length vs. Diameter)	P – value
0.020 vs. 0.022	P=0.3
0.020 vs. 0.028	P<0.0001
0.022 vs. 0.028	P<0.0001

There was a statistically highly significant difference between the means of the LDR at 40g of the 0.028 to that of the 0.022 and 0.020 wire diameters (P<0.0001) as shown in table 4.8. There was not a statistically significant difference between the means of the LDR at 40g of the 0.020 and 0.022 diameter wires (P=0.3). Fig 4.3 is a graphic illustration of the experiment results. LDR increased as the diameter of spring increased and decreased as the length of the spring increased. LDR was directly proportional to diameter and inversely proportional to length. LDR was higher for the 0.028 diameter wire as compared to the 0.022 and 0.020 diameter wire. There was not much difference between the LDR for the 0.020 and 0.022 diameter wires.

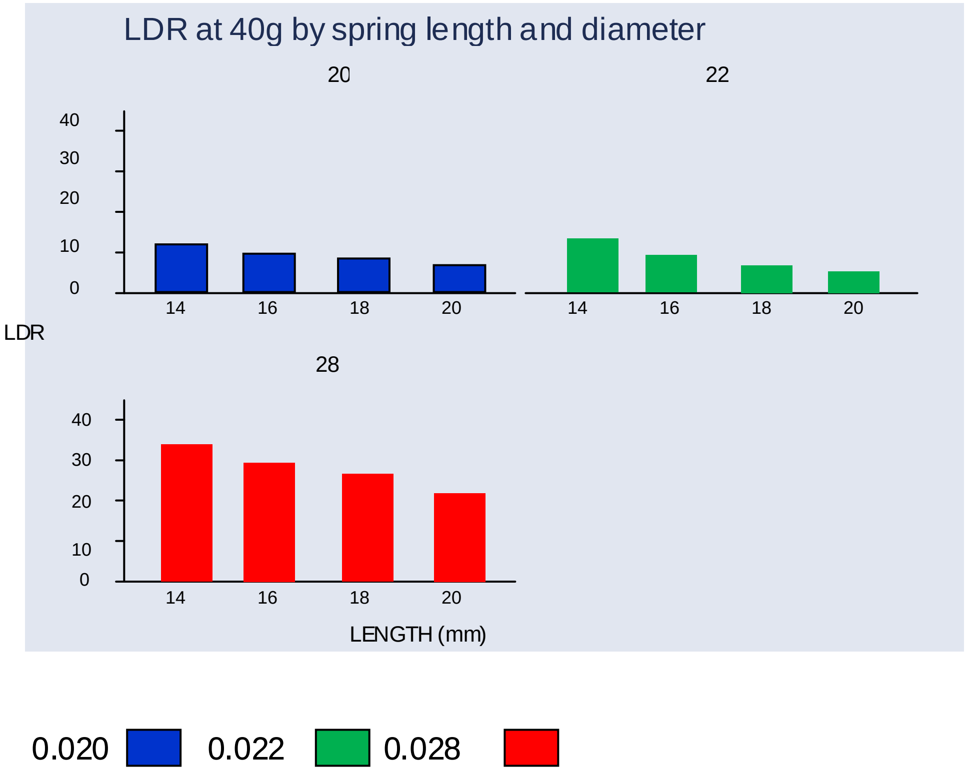

Fig 4.3 LDR at 40g for spring length and diameter.

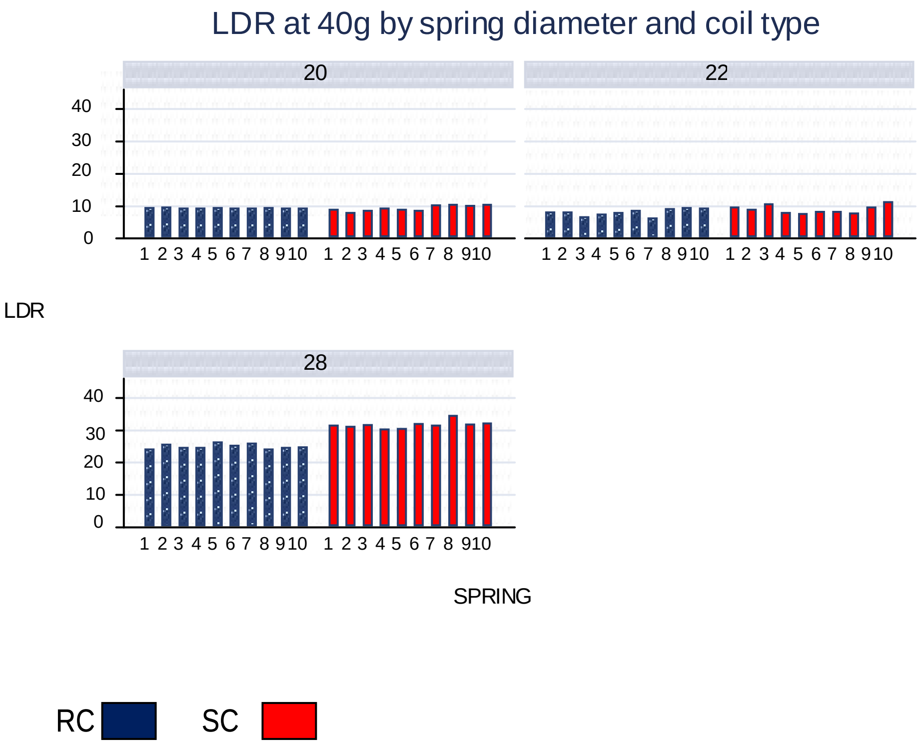

Figure 4.4 LDR at 40g for individual springs for diameter and coil type

Fig 4.4 is a graphic representation of the experiment representing the LDR of the individual retractors for both the SC and RC. The LDR of the 0.028 diameter wires for both the SC and RC were higher than those of the 0.020 and 0.022 diameter wires. The LDR measurements SC of the 0.028 diameter wires were higher than those of the RC. There was not much difference in the LDR measurements of 0.020 and 0.022 diameter wires for both the SC and RC.

CHAPTER 5

DISCUSSION

LDR for the 0.020 diameter wire

LDR was measured at 40g for 0.020 diameter wire at 14, 16, 18 and 20mm lengths for the SC and RC. There was an inverse relationship between LDR and wire length for the SC and RC.

LDR for the 0.022 diameter wire

LDR was measured at 40g for 0.022 diameter wire at 14, 16, 18 and 20mm lengths for the SC and RC. There was an inverse relationship between LDR and wire length for the SC and RC.

LDR for the 0.028 diameter wire

LDR was measured at 40g for 0.028 diameter wire at 14, 16, 18 and 20mm lengths for the SC and RC. There was an inverse relationship between LDR and wire length for the SC and RC.

Comparison of LDR at 40g by diameter

There was no statistically significant difference between the LDR at 40g for the 0.020 and 0.022 diameter wires (P value < 0.05) for both the SC and RC. Moyers (1988) reported that increasing the diameter of the wire leads to an increase in the LDR. There was a statistically significant difference between the LDR at 40g for the 0.020 and 0.022 diameter wires when compared to the 0.028 diameter wires (P values < 0.001) for both the SC and RC. There was a significant difference in the LDR of the 0.028 diameter wires for the RC and SC with the latter showing higher LDR values than the former. This is in agreement with the findings that were made by Zietsman, Visagie and Coetzee (2000), who compared two types of coil springs and found the reverse coil spring to be a better choice clinically in terms of LDR values.

Comparison of LDR by wire length

The other important factor that was examined was the effect of spring length versus LDR. The finding was that there was an inverse proportional relationship between spring length and LDR. This is in agreement with other studies that were done with springs (Zietsman and Du Toit, 2002). Moyers (1988) also showed the load-deflection rate varies inversely with the length; in other words, the longer the cantilever, the lower the load-deflection rate. Adding length within the practical confines of the oral cavity is an excellent way to improve spring properties (Proffit, 2007).

Increasing the length of a wire with vertical loops is one of the more effective means of reducing load-deflection rates for active members of the appliance and, at the same time, only minimally altering their maximal elastic loads. However, limitations exist on how much the length can be increased. Vertical segments in the wire are limited by occlusion and the extension of the mucobuccal fold. Placing coils in the retractor is a means of increasing the length of the wire (Proffit and Fields, 2007).

Comparison of LDR by coil type

In this study, the reverse coil type performed better compared to the standard coil. The RC showed lower LDR values when measured at the same lengths than the SC. This could be attributed to the increased length of the coil of the reverse coil retractor (Moyers, 1988; Proffit and Fields, 2007).

Burstone (1994) advocates a low LDR to accomplish desirable stress levels in the periodontal ligament and for greater accuracy in controlling the magnitude of the force. Forces and moments produced by an orthodontic appliance are the critical elements at the clinical level of observation. Specifically of interest are three important characteristics involving active and reactive members: (1) the M/F ratio, (2) the load-deflection rate, and (3) the maximal force or moment of any component of the appliance. As the LDR declines for a tooth that is moving under a continuous force, the change in force value is reduced.

A low load-deflection rate is desirable in active components for two important reasons: (1) a mechanism with a low load-deflection rate maintains a more desirable stress level in the PDL because the force on a tooth does not radically change magnitude every time the tooth has been displaced; and (2) a member with a low load-deflection rate offers greater accuracy in controlling force magnitude.s. Active components with low load-deflection rates require long ranges of activation to build up to optimal force values; hence they give the clinician greater control over the magnitude of force used (Moyers, 1988).

If a low load-deflection rate is desirable for the active component of the appliance, the opposite is true for the reactive component. The reactive component of the appliance should be relatively rigid; that is, it should have a high load-deflection rate.

My study assessed this important factor of an orthodontic appliance. The ideal orthodontic wire for an active member is one that gives a high maximal elastic load (EL) and a low load-deflection rate (Moyers, 1988). The optimum orthodontic tooth movement is produced by a light continuous force that does not decrease too rapidly and this can be achieved to a certain extent by a removable appliance if worn daily for a considerable period of time (Proffit and Fields, 2007). The 0.028 wire has a higher LDR which basically means that the wire is delivering a higher force for a short span of time and an inference that can be made from this is that the wire is actually decreasing the rate of tooth movement compared to the 0.022 and 0.020.

CHAPTER 6

CONCLUSIONS

The purpose of the study was to determine the force delivery of buccal canine retractors of smaller diameter wires, namely 0.020 inch (0.51mm) and 0.022 inch (0.56mm) [Unitek®], make and to compare the LDR of a standard coil retractor versus a reverse coil retractor, in order to determine which would be clinically the most effective. The 0.028 (0.7mm) inch wire was used as a control sample.

The results of the study showed that the there was no statistically significant difference between the mean LDR values of the 0.020 and 0.022 wires. The 0.028 diameter wire showed a statistically significant difference when compared to the 0.020 and 0.022 wires-the LDR values were significantly higher than the LDR values of the 0.020 and 0.022 wires. The LDR phenomenon as explained by Moyers (1988) is an indication of the force delivery of the wire. A wire with a high LDR value will transmit a high force for a short span of time compared to a wire with a low LDR value which will transmit a low force over a longer time. The clinical relevance of this will be the ability of the smaller diameter wires to transmit lower forces over longer periods which will lead to increase in rate of tooth movement. It was therefore concluded that the smaller diameter wire (0.020 and 0.022) would be a better choice wire in the manufacturing of canine retractors, as the lower LDR represents lower, more continuous force levels. No statistical difference was found between the standard and reverse curved retractors of smaller diameter wires, and it was therefore concluded that no clinical preference can be given to either design.

The results also indicated that increasing the length of the wire lowers the LDR. The length of the buccal retractor is determined by the depth of the muccobuccal fold. Using the 0.028 wire to fabricate the retractor, it is necessary to add additional wire to decrease the LDR and improve deflection. Wire length is restricted by the confines of the muccobuccal fold, increasing the length can lead to irritation of the mucosa, and it has been experienced in many clinical scenarios. Using the smaller diameter wires (0.022 or 0.020) will be of clinical benefit since they are easier to deflect, and do not have to be make use of increased length to reduce their stiffness. In cases where a patient has a shallow muccobuccal fold, shorter length 0.022 or 0.020 wires can be used to avoid irritation of the muccobuccal fold.

Null hypothesis (Ho1) stated that the force delivery of smaller diameter wires is clinically more efficient than that of 0.028 diameter wires. In light of the findings of this study, the null hypothesis was accepted.

Null hypothesis (Ho2) stated that there should not be a significant difference between the force deliveries of the 0.020 and 0.022 diameter wires. In light of the findings of this study, null hypothesis (Ho2) was accepted.

The current study was an in vitro study, and a follow up study will be necessary to examine these findings clinically. This can be done by using buccal retractors in the same patient fabricated from different wire sizes for retraction of the canines, and assessing the rate of tooth movements on both sides. A structured approach to future research is necessary to supplement the results and conclusions from this study.

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ADDENDUM A

Experimental measurements and calculations of the load deflection rate (LDR): Raw data.

Coil_type	Diameter	Spr_ID	Spr_length	rep_1	rep_2	rep_3	Mean	Actual	LDR_40
1	20	1	20	37.5	37.5	37.5	37.5	5.250	7.619
1	20	1	18	34.0	34.0	34.0	34.0	4.760	8.403
1	20	1	16	29.0	29.0	29.0	29.0	4.060	9.852
1	20	1	14	24.5	23.8	23.8	24.0	3.360	11.905
1	20	2	20	36.5	37.5	37.5	37.2	5.203	7.687
1	20	2	18	32.8	34.0	34.0	33.6	4.702	8.508
1	20	2	16	28.0	29.0	29.0	28.7	4.013	9.967
1	20	2	14	23.0	24.0	24.0	23.7	3.313	12.072
1	20	3	20	38.0	38.5	38.0	38.2	5.343	7.486
1	20	3	18	34.5	35.5	34.5	34.8	4.877	8.202
1	20	3	16	29.8	30.0	30.0	29.9	4.188	9.550
1	20	3	14	24.8	24.8	24.8	24.8	3.465	11.544
1	20	4	20	38.5	39.5	39.0	39.0	5.460	7.326
1	20	4	18	34.0	34.5	34.0	34.2	4.783	8.362
1	20	4	16	29.5	29.5	29.5	29.5	4.130	9.685
1	20	4	14	24.5	24.5	24.5	24.5	3.430	11.662
1	20	5	20	37.5	37.5	37.5	37.5	5.250	7.619
1	20	5	18	34.0	34.0	34.0	34.0	4.760	8.403
1	20	5	16	29.0	29.0	29.0	29.0	4.060	9.852
1	20	5	14	24.5	23.8	23.8	24.0	3.360	11.905
1	20	6	20	38.0	38.5	38.0	38.2	5.343	7.486
1	20	6	18	34.5	35.5	34.5	34.8	4.877	8.202
1	20	6	16	29.8	30.0	30.0	29.9	4.188	9.550
1	20	6	14	24.8	24.8	24.8	24.8	3.465	11.544
1	20	7	20	37.5	37.5	38.0	37.7	5.273	7.585
1	20	7	18	34.0	34.0	34.5	34.2	4.783	8.362
1	20	7	16	28.8	29.0	29.0	28.9	4.048	9.881
1	20	7	14	25.0	24.8	24.8	24.8	3.477	11.505
1	20	8	20	37.5	37.8	37.5	37.6	5.262	7.602
1	20	8	18	34.0	34.0	34.5	34.2	4.783	8.362
1	20	8	16	28.5	29.0	28.8	28.8	4.025	9.938

1	20	8	14	24.5	24.8	24.8	24.7	3.453	11.583
1	20	9	20	37.8	37.8	37.5	37.7	5.273	7.585
1	20	9	18	34.0	34.5	34.5	34.3	4.807	8.322
1	20	9	16	29.0	29.0	29.0	29.0	4.060	9.852
1	20	9	14	24.5	24.8	24.8	24.7	3.453	11.583
1	20	10	20	38.0	38.0	37.8	37.9	5.308	7.535
1	20	10	18	34.5	34.5	34.5	34.5	4.830	8.282
1	20	10	16	29.5	29.5	29.5	29.5	4.130	9.685
1	20	10	14	24.8	24.5	24.5	24.6	3.442	11.622
2	20	1	20	34.8	34.5	34.5	34.6	6.917	5.783
2	20	1	18	32.0	30.0	30.5	30.8	5.550	7.207
2	20	1	16	25.8	25.5	25.5	25.6	4.093	9.772
2	20	1	14	22.0	21.8	21.8	21.8	3.057	13.086
2	20	2	20	37.0	37.5	37.0	37.2	7.433	5.381
2	20	2	18	34.3	34.3	34.3	34.3	6.165	6.488
2	20	2	16	29.8	29.5	29.5	29.6	4.733	8.451
2	20	2	14	25.5	25.0	25.0	25.2	3.523	11.353
2	20	3	20	34.5	34.5	34.5	34.5	6.900	5.797
2	20	3	18	31.0	31.5	31.0	31.2	5.610	7.130
2	20	3	16	27.0	26.8	27.0	26.9	4.307	9.288
2	20	3	14	23.5	22.5	23.0	23.0	3.220	12.422
2	20	4	20	33.0	33.5	33.0	33.2	6.633	6.030
2	20	4	18	29.3	29.8	29.5	29.5	5.310	7.533
2	20	4	16	25.3	25.5	25.5	25.4	4.067	9.836
2	20	4	14	21.0	21.0	21.0	21.0	2.940	13.605
2	20	5	20	34.8	34.5	34.5	34.6	6.917	5.783
2	20	5	18	32.0	30.0	30.5	30.8	5.550	7.207
2	20	5	16	25.8	25.5	25.5	25.6	4.093	9.772
2	20	5	14	22.0	21.8	21.8	21.8	3.057	13.086
2	20	6	20	34.5	34.5	34.5	34.5	6.900	5.797
2	20	6	18	31.0	31.5	31.0	31.2	5.610	7.130
2	20	6	16	27.0	26.8	27.0	26.9	4.307	9.288
2	20	6	14	23.5	22.5	23.0	23.0	3.220	12.422
2	20	7	20	34.3	34.5	34.5	34.4	4.818	8.302
2	20	7	18	30.0	29.5	29.5	29.7	4.153	9.631
2	20	7	16	26.8	26.5	26.5	26.6	3.722	10.748
2	20	7	14	22.5	22.5	22.8	22.6	3.162	12.652
2	20	8	20	34.5	34.8	34.5	34.6	4.842	8.262

2	20	8	18	30.5	30.8	30.8	30.7	4.293	9.317
2	20	8	16	25.5	25.5	25.8	25.6	3.582	11.168
2	20	8	14	21.8	21.8	22.0	21.8	3.057	13.086
2	20	9	20	35.0	35.0	35.3	35.1	4.912	8.144
2	20	9	18	30.8	30.8	30.8	30.8	4.305	9.292
2	20	9	16	26.8	27.0	26.8	26.8	3.757	10.648
2	20	9	14	22.5	23.0	22.5	22.7	3.173	12.605
2	20	10	20	34.5	34.5	34.5	34.5	4.830	8.282
2	20	10	18	30.5	30.5	30.5	30.5	4.270	9.368
2	20	10	16	25.5	25.8	25.5	25.6	3.582	11.168
2	20	10	14	21.8	21.8	21.8	21.8	3.045	13.136
1	22	1	20	37.5	37.0	37.5	37.3	7.467	5.357
1	22	1	18	33.5	33.5	33.5	33.5	6.030	6.633
1	22	1	16	28.0	28.0	28.0	28.0	4.480	8.929
1	22	1	14	24.5	24.0	24.5	24.3	3.407	11.742
1	22	2	20	37.5	38.0	37.5	37.7	7.533	5.310
1	22	2	18	33.5	33.5	33.5	33.5	6.030	6.633
1	22	2	16	28.5	28.5	28.5	28.5	4.560	8.772
1	22	2	14	23.5	23.5	24.5	23.8	3.337	11.988
1	22	3	20	39.0	39.5	39.0	39.2	7.833	5.106
1	22	3	18	38.5	38.8	38.5	38.6	6.945	5.760
1	22	3	16	35.0	35.5	35.0	35.2	5.627	7.109
1	22	3	14	34.5	34.5	34.8	34.6	4.842	8.262
1	22	4	20	40.5	40.0	40.0	40.2	8.033	4.979
1	22	4	18	36.0	36.5	37.0	36.5	6.570	6.088
1	22	4	16	31.0	30.5	30.5	30.7	4.907	8.152
1	22	4	14	26.5	26.5	26.5	26.5	3.710	10.782
1	22	5	20	38.5	38.5	38.8	38.6	7.717	5.184
1	22	5	18	34.5	34.8	34.5	34.6	6.225	6.426
1	22	5	16	29.5	29.5	29.5	29.5	4.720	8.475
1	22	5	14	24.5	24.5	24.5	24.5	3.430	11.662
1	22	6	20	36.5	36.8	36.5	36.6	7.317	5.467
1	22	6	18	32.5	32.8	32.5	32.6	5.865	6.820
1	22	6	16	26.8	26.8	26.5	26.7	4.267	9.375
1	22	6	14	22.5	22.5	22.5	22.5	3.150	12.698
1	22	7	20	46.0	46.5	46.5	46.3	9.267	4.317
1	22	7	18	41.5	42.0	42.0	41.8	7.530	5.312
1	22	7	16	37.8	37.5	37.5	37.6	6.013	6.652

1	22	7	14	32.5	33.0	33.0	32.8	4.597	8.702
1	22	8	20	34.5	34.5	34.8	34.6	6.917	5.783
1	22	8	18	30.5	30.5	30.5	30.5	5.490	7.286
1	22	8	16	25.8	25.8	25.8	25.8	4.120	9.709
1	22	8	14	21.5	21.5	21.5	21.5	3.010	13.289
1	22	9	20	37.5	37.5	37.5	37.5	5.250	7.619
1	22	9	18	34.8	34.8	34.5	34.7	4.853	8.242
1	22	9	16	28.5	28.8	28.8	28.7	4.013	9.967
1	22	9	14	24.5	24.8	24.5	24.6	3.442	11.622
1	22	10	20	38.0	38.8	38.8	38.5	5.390	7.421
1	22	10	18	34.8	34.8	34.5	34.7	4.853	8.242
1	22	10	16	28.5	28.5	28.5	28.5	3.990	10.025
1	22	10	14	24.5	24.5	24.5	24.5	3.430	11.662
2	22	1	20	32.5	32.5	32.5	32.5	6.500	6.154
2	22	1	18	28.5	28.5	28.5	28.5	5.130	7.797
2	22	1	16	23.8	24.5	24.5	24.3	3.880	10.309
2	22	1	14	19.5	20.5	20.5	20.2	2.823	14.168
2	22	2	20	34.5	34.5	34.5	34.5	6.900	5.797
2	22	2	18	29.5	30.5	30.5	30.2	5.430	7.366
2	22	2	16	26.5	26.5	26.5	26.5	4.240	9.434
2	22	2	14	22.0	22.0	22.0	22.0	3.080	12.987
2	22	3	20	32.0	32.5	32.0	32.2	6.433	6.218
2	22	3	18	26.5	26.5	26.0	26.3	4.740	8.439
2	22	3	16	21.5	21.5	21.5	21.5	3.440	11.628
2	22	3	14	18.0	18.0	18.0	18.0	2.520	15.873
2	22	4	20	38.5	38.5	39.0	38.7	7.733	5.172
2	22	4	18	33.5	33.5	33.5	33.5	6.030	6.633
2	22	4	16	29.5	29.5	29.5	29.5	4.720	8.475
2	22	4	14	24.5	24.5	24.5	24.5	3.430	11.662
2	22	5	20	39.5	39.0	38.8	39.1	7.817	5.117
2	22	5	18	35.0	35.0	35.0	35.0	6.300	6.349
2	22	5	16	31.5	31.5	31.5	31.5	5.040	7.937
2	22	5	14	25.5	25.5	25.5	25.5	3.570	11.204
2	22	6	20	36.0	36.5	36.5	36.3	7.267	5.505
2	22	6	18	32.5	32.5	32.5	32.5	5.850	6.838
2	22	6	16	28.5	28.5	28.5	28.5	4.560	8.772
2	22	6	14	24.5	24.5	24.5	24.5	3.430	11.662
2	22	7	20	36.0	35.8	36.0	35.9	7.183	5.568

2	22	7	18	32.0	33.5	33.5	33.0	5.940	6.734
2	22	7	16	28.0	28.0	28.0	28.0	4.480	8.929
2	22	7	14	23.8	23.8	23.8	23.8	3.325	12.030
2	22	8	20	39.5	39.0	39.5	39.3	7.867	5.085
2	22	8	18	35.0	35.0	35.0	35.0	6.300	6.349
2	22	8	16	31.8	31.5	31.5	31.6	5.053	7.916
2	22	8	14	24.8	25.0	25.0	24.9	3.488	11.467
2	22	9	20	36.0	35.5	35.5	35.7	4.993	8.011
2	22	9	18	33.8	33.5	33.5	33.6	4.702	8.508
2	22	9	16	28.5	28.0	28.0	28.2	3.943	10.144
2	22	9	14	23.5	23.8	23.8	23.7	3.313	12.072
2	22	10	20	34.8	34.8	34.8	34.8	4.865	8.222
2	22	10	18	28.5	28.5	28.5	28.5	3.990	10.025
2	22	10	16	23.8	23.5	23.5	23.6	3.302	12.115
2	22	10	14	19.5	20.0	19.8	19.8	2.765	14.467
1	28	1	20	15.0	15.0	15.0	15.0	2.100	19.048
1	28	1	18	13.0	12.8	13.0	12.9	1.808	22.120
1	28	1	16	11.3	11.3	11.0	11.2	1.563	25.586
1	28	1	14	9.8	9.8	9.8	9.8	1.365	29.304
1	28	2	20	13.8	14.0	14.0	13.9	1.948	20.530
1	28	2	18	11.8	11.8	11.8	11.8	1.645	24.316
1	28	2	16	10.5	10.5	10.5	10.5	1.470	27.211
1	28	2	14	9.5	9.5	9.5	9.5	1.330	30.075
1	28	3	20	14.5	14.5	14.8	14.6	2.042	19.592
1	28	3	18	12.8	12.5	12.8	12.7	1.773	22.556
1	28	3	16	11.0	11.0	11.0	11.0	1.540	25.974
1	28	3	14	9.5	9.5	9.5	9.5	1.330	30.075
1	28	4	20	14.5	14.5	14.8	14.6	2.042	19.592
1	28	4	18	12.5	12.5	12.8	12.6	1.762	22.706
1	28	4	16	10.8	11.0	11.0	10.9	1.528	26.172
1	28	4	14	9.5	9.5	9.5	9.5	1.330	30.075
1	28	5	20	13.0	13.5	13.0	13.2	1.843	21.700
1	28	5	18	12.0	12.0	12.0	12.0	1.680	23.810
1	28	5	16	10.5	10.5	10.5	10.5	1.470	27.211
1	28	5	14	8.8	8.8	9.0	8.8	1.239	32.296
1	28	6	20	14.5	14.5	14.8	14.6	2.042	19.592
1	28	6	18	12.5	12.5	12.0	12.3	1.727	23.166
1	28	6	16	10.8	10.5	10.5	10.6	1.482	26.997

1	28	6	14	9.0	9.0	9.5	9.2	1.283	31.169
1	28	7	20	13.8	13.8	13.8	13.8	1.925	20.779
1	28	7	18	12.0	12.0	11.8	11.9	1.668	23.976
1	28	7	16	10.5	10.8	10.8	10.7	1.493	26.786
1	28	7	14	8.8	8.8	9.0	8.8	1.237	32.345
1	28	8	20	15.0	15.0	14.8	14.9	2.088	19.154
1	28	8	18	12.8	12.8	12.8	12.8	1.785	22.409
1	28	8	16	11.5	11.5	11.5	11.5	1.610	24.845
1	28	8	14	9.5	9.5	9.5	9.5	1.330	30.075
1	28	9	20	14.5	14.5	14.5	14.5	2.030	19.704
1	28	9	18	12.5	12.5	12.8	12.6	1.762	22.706
1	28	9	16	11.0	11.0	11.0	11.0	1.540	25.974
1	28	9	14	9.5	9.5	9.5	9.5	1.330	30.075
1	28	10	20	14.0	14.5	14.5	14.3	2.007	19.934
1	28	10	18	12.5	12.5	12.5	12.5	1.750	22.857
1	28	10	16	11.0	10.8	10.8	10.8	1.517	26.374
1	28	10	14	9.8	9.5	9.5	9.6	1.342	29.814
2	28	1	20	11.5	11.5	11.5	11.5	1.610	24.845
2	28	1	18	9.8	9.5	9.5	9.6	1.342	29.814
2	28	1	16	8.5	8.5	8.5	8.5	1.190	33.613
2	28	1	14	7.8	7.5	7.5	7.6	1.062	37.677
2	28	2	20	12.0	11.8	11.8	11.8	1.657	24.145
2	28	2	18	10.0	10.5	10.5	10.3	1.447	27.650
2	28	2	16	8.5	8.5	8.0	8.3	1.167	34.286
2	28	2	14	7.5	7.5	7.5	7.5	1.050	38.095
2	28	3	20	11.5	11.5	11.5	11.5	1.610	24.845
2	28	3	18	9.5	9.5	9.8	9.6	1.342	29.814
2	28	3	16	8.5	8.5	8.5	8.5	1.190	33.613
2	28	3	14	7.5	7.5	7.5	7.5	1.050	38.095
2	28	4	20	12.0	12.0	11.8	11.9	1.668	23.976
2	28	4	18	11.0	11.0	11.0	11.0	1.540	25.974
2	28	4	16	9.0	8.8	8.8	8.8	1.237	32.345
2	28	4	14	7.5	7.5	7.3	7.4	1.038	38.523
2	28	5	20	11.5	11.8	11.8	11.7	1.633	24.490
2	28	5	18	10.5	10.5	10.5	10.5	1.470	27.211
2	28	5	16	9.0	9.0	8.8	8.9	1.248	32.043
2	28	5	14	7.5	7.5	7.5	7.5	1.050	38.095
2	28	6	20	11.5	11.3	11.3	11.3	1.587	25.210

2	28	6	18	9.5	9.5	9.5	9.5	1.330	30.075
2	28	6	16	8.5	8.5	8.5	8.5	1.190	33.613
2	28	6	14	7.3	7.5	7.5	7.4	1.038	38.523
2	28	7	20	12.0	11.8	11.8	11.8	1.657	24.145
2	28	7	18	9.8	9.8	9.8	9.8	1.365	29.304
2	28	7	16	8.5	8.5	8.5	8.5	1.190	33.613
2	28	7	14	7.5	7.3	7.5	7.4	1.038	38.523
2	28	8	20	11.8	11.8	11.8	11.8	1.645	24.316
2	28	8	18	10.5	10.5	1O.5	7.0	0.980	40.816
2	28	8	16	8.0	8.5	8.5	8.3	1.167	34.286
2	28	8	14	7.5	7.5	7.5	7.5	1.050	38.095
2	28	9	20	11.5	11.5	11.8	11.6	1.622	24.666
2	28	9	18	9.5	9.5	9.5	9.5	1.330	30.075
2	28	9	16	8.8	8.5	8.5	8.6	1.202	33.287
2	28	9	14	7.5	7.0	7.5	7.3	1.027	38.961
2	28	10	20	11.8	11.8	11.5	11.7	1.633	24.490
2	28	10	18	9.5	9.5	9.5	9.5	1.330	30.075
2	28	10	16	8.5	8.0	8.0	8.2	1.143	34.985
2	28	10	14	7.5	7.5	7.0	7.3	1.027	38.961